

Assessment of Ecologically Engineered Stormwater Management

INTRODUCTION

This study, funded through the FCM Green Municipal Funds with additional financial support from CMHC, evaluated how five engineered wetland installations and stream restoration projects affected stormwater quality. Projects varied in age and size, but all were built to reduce the negative effects of stormwater on local streams, and all were designed and constructed by the same company within the District of Saanich, B.C., as tributaries of the Colquitz River.

The following projects were studied:

- *Willowbrook subdivision*, where wetlands were constructed to capture stormwater from an in-fill residential development, and Swan Creek, a ditched channel, was restored to a functioning creek.
- *Glanford Station*, where a small wetland was installed to capture stormwater from a subdivision before draining into Swan Creek, just downstream from the Willowbrook installation.
- *Baxter Pond*, where a dry detention pond was rehabilitated into a wetland and now accommodates stormwater from a new subdivision, a portion of highway, and a nearby school.
- *Blenkinsop Creek*, where approximately 650 m of ditched channel was rehabilitated into a stream to create natural habitat, attenuate flood flows, and reduce soil erosion and nutrient input from a neighbouring farm.

- *Leeds Creek*, where a stream channel and shallow pond complex were reconstructed to alleviate flooding of a nearby subdivision.

METHODOLOGY

Owing to the isolation of the study sites and budget limitations, this study relied on grab samples instead of the more common well samples and continuous monitoring used in similar investigations. Where possible, samples were taken upstream and downstream of each receiving or reconstructed stream section, as well as at the inlet and outlet of wetland installations.

Samples were collected over 14 months, and during storm events when possible. On-site water analyses using a handheld multi-meter were conducted monthly between October 2006 and July 2007, and again in December 2007. Laboratory water samples for chemistry, bacteriology and metal analyses were also collected monthly, except in summer when water levels were too low. Sediment samples were collected three times: fall 2006, spring 2007, and fall 2007.

Test parameters included:

- *On-site water analyses*: dissolved oxygen, conductance, pH, temperature.
- *Water chemistry analyses*: alkalinity, ammonia, biochemical oxygen demand (May only), chloride, colour, conductivity (at 25° C), hardness, total Kjeldahl nitrogen (TKN), nitrate, nitrite, ortho-phosphate (ortho-P), pH, phenols (May only), total extractable, hydrocarbons, total dissolved solids (TDS), total suspended solids (TSS).

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- *Water Bacteriology analyses:* fecal coliforms, Enterococci
- *Water and sediment metal analyses:* aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chromium, cobalt, copper, gold, iron, lanthanum, lead, magnesium, manganese, mercury, molybdenum, nickel, phosphorus, potassium, scandium, selenium, silicon, silver, sodium, strontium, tin, titanium, tungsten, vanadium, zinc.

Precipitation data was collected from University of Victoria meteorological stations near each site. Both a field and laboratory quality assurance program was implemented to ensure that the data collected were as accurate and precise as possible.

Water and sediment data collected were compared to the Canadian Water Quality Guidelines for the Protection of Aquatic Life, and bacteriological results were measured against the Guidelines for Canadian Recreational Water Quality. Mean influent and effluent values were compared with those listed in the International Stormwater Best Management Practices Database (BMP database)¹, which contains searchable information on more than 200 stormwater studies.

RESULTS

Precipitation

Total precipitation during the sampling period was normal, but was characterized by long dry periods interspersed by large rain and snow events.

Willowbrook Subdivision

Stream data were complicated by additional water inputs along the stream length, and so the analysis focused only on water quality upstream and downstream, and at the inlet and outlet of the main wetland.

Test results:

- *Nutrients:* On average, the wetland removed 17% total nitrogen (ammonia, nitrate, nitrite and Total Kjeldahl Nitrogen). However, between inlet and outlet, ortho-P concentrations increased by 1,103%.
- *Total dissolved solids:* The wetland had an average removal efficiency of 32.7% for TDS and 21.7% for chloride (discounting October's anomalous increase).
- *Suspended solids:* While historically the wetland appears to have been very effective at removing sediment (large accumulations were observed), increased levels of TSS and turbidity in the outflow indicate that stormwater is now mobilizing accumulated sediment and discharging it into the creek.
- *Temperature:* Temperatures dropped 2.7°C on average before entering Swan Creek.
- *Metals:* Arsenic, copper, lead, mercury, sodium, tin and zinc were all lower at the outlet than at the inlet in the fall of 2006. With the onset of winter rains, metal values at the outlet began to exceed those at the inlet, except in the case of sodium, suggesting mobilization from wetland sediments.
- *Sediment Chemistry:* Sediments at the outlet had lower concentrations of all key metals (arsenic, cadmium, chromium, copper, lead, mercury, sodium and zinc) on all three sampling dates with a few exceptions. In October 2006, arsenic and mercury were slightly higher at the outlet than the inlet, and in March 2007, cadmium, lead, sodium and zinc were all higher at the inlet than the outlet, suggesting that sediments might have migrated from the inlet area during higher rainfall.
- *Bacteriology:* The maximum number of fecal coliforms recorded at the inlet was 2,600 CFU/100 mL, and no Enterococci were detected.

¹ The BMP database is sponsored by the Water Environment Research Foundation (WERF), the American Society of Civil Engineers (ASCE) / Environmental and Water Resources Institute (EWRI), the American Public Works Association (APWA), the Federal Highway Administration (FHWA), and the U.S. Environmental Protection Agency (EPA), and is available at (www.bmpdatabase.org).

Compliance:

- *Water:* The pond's copper levels were about ten times the guidelines, and while outlet waters were in compliance with lead, inlet waters were not. Allowable zinc levels were exceeded twice at the inlet.
- *Sediment:* Chromium, copper and zinc guidelines were exceeded at the inlet and outlet on all sample dates. Lead levels also exceeded on two occasions, and mercury once, in both locations.
- *Bacteriology:* In compliance.

Summary: The Willowbrook wetland effectively removed heat, nitrogen, TDS and chloride, but exported ortho-P. The wetland generally acted as a sink for metals during low flow summer periods, and exported metals during rainy winter months. Observations of accumulated sediment suggest that the wetland could be made more effective if it were more regularly maintained.

Glanford Wetland:

Analyses focused on the inlet and outlet of this small wetland which is downstream of the Willowbrook system.

Test results:

- *Nutrients:* Total nitrogen was reduced by 38.6%, and a small amount of ortho-P was exported.
- *Total dissolved solids:* Chloride concentration, TDS, and specific conductance decreased on average, but only slightly.



Figure 1 View of wetland between Willowbrook and Glanford 2003

- *Total suspended solids:* Average TSS and turbidity removal rates were 28% and 42.7%, respectively.
- *Temperature:* Temperature decreased from inlet to outlet by 1° C on average, likely owing to plant evapotranspiration.
- *Metals:* Arsenic, chromium, lead, mercury, tin and zinc were all lower at the outlet than at the inlet, with few exceptions. Average reduction of sodium and zinc was 4.1 % and 24.9%, respectively.
- *Sediment Chemistry:* Sediment samples were inconsistent, although wetland sediments at the outlet were lower on average in arsenic, iron, mercury, sodium, lead and tin.
- *Bacteriology:* Fecal coliforms reached 1,200 CFU/100 mL at the inlet on June 11, 2007, at which time there were 144 CFU/100mL Enterococcus.

Compliance:

- *Water:* Copper levels in all locations were ten times the allowable guideline, and lead levels were also exceeded at the inlet. Zinc levels were higher than allowable on isolated occasions at both the inlet and outlet.
- *Sediment:* Glanford exceeded chromium, copper and zinc guidelines on all sample dates, and lead and arsenic levels on two occasions, at both the inlet and outlet. Mercury was exceeded twice at the inlet.
- *Bacteriology:* In compliance.

Summary: The Glanford wetland was effective at removing heat, TSS, metals, and both nitrogen and ortho-P, but did little to remove dissolved materials, likely because of its small size and short residence time. Still, its TDS and metals removal rate was significantly higher than Willowbrook's, a much larger wetland, which was probably because Glanford was recently dredged. Outlet sediments generally had a lower metals concentrations at the inlet, however results were inconsistent, possibly because some sediment was disturbed when the pond was cleaned out.

Baxter Pond

Test Results:

- *Nutrients:* Baxter Pond's total nitrogen removal efficiency varied throughout the year, but was 40.8% on average, and ortho-P was generally exported.
- *Total dissolved solids:* Other than on two occasions, TDS and conductivity decreased through the pond. Chloride and sodium concentrations spiked in December and January from road salt.
- *Total suspended solids:* Baxter Pond was very effective at removing large, heavier particles following winter snowstorms, but finer material did not readily settle out. As a consequence, outlet TSS values were higher than those at the inlet on seven out of ten occasions.
- *Temperature:* Temperature declined by an average of 2.1°C.
- *Metals:* Because of the pond's proximity to the highway, there were large spikes of chromium, sodium, and zinc, as well as a smaller peak of mercury after snow melt. The pond was effective at reducing sodium and, to a lesser extent, mercury and zinc. Between the inlet and the middle of the pond, levels of cadmium, chromium, mercury, lead and zinc declined, but increased again at the outlet, most likely because of Gabo Creek backflowing into the wetland during low flows.
- *Sediment chemistry:* Again, metal concentrations generally reduced from the inlet to the middle of pond, but then sharply increased at the outlet.
- *Bacteriological:* Both fecal coliforms and Enterococci in Baxter Pond were very low, considering the population of ducks living on the pond.

Compliance:

- *Water:* Outlet waters exceeded guidelines for arsenic on one occasion. Chromium levels were exceeded in all samples in January 2007, and at the outlet in March, but were not detectable otherwise. Baxter Pond exceeded copper guidelines on all measurable occasions.
- *Sediment:* Outlet sediments exceeded arsenic guidelines on two occasions, mercury on one occasion, and cadmium, lead and zinc on all three sample dates. At the inlet, Cadmium was also exceeded once, lead twice, and zinc always. Zinc was also exceeded mid-pond on one date. Six of the nine samples exceeded levels for chromium, and all but one exceeded for copper.
- *Bacteriology:* In compliance.

Summary: Baxter Pond is an important thermal buffer for Gabo creek and is also effective at removing dissolved substances, large suspended sediments, and nitrogen, but was an exporter of ortho-P. Water in the middle of the pond had lower metals concentrations than the inlet, but these values rose again at the outlet suggesting backwatering, resuspension of sediment, or both. While the pond may be effective at initially trapping finer sediments, waterfowl in the pond may stir it up so that it washes downstream into Gabo Creek. They do not, however, seem to be adding to the fecal coliform burden in the water, which is surprising given their large number.

Blenkinsop Creek

The analysis for Blenkinsop Creek was complicated by multiple inputs, some seasonal, some from Cumberland Creek backwash and others from Galeys' field drain. For this reason, data analysis focused on the water quality differences between the most upstream site at the outlet of Blenkinsop Lake, and the midpoint of Galeys' field, which is approximately 250 m downstream.

Test results:

- *Nutrients:* Blenkinsop Creek removed both nitrogen and ortho-P.
- *Total dissolved solids:* Specific conductance and TDS were largely unchanged along the length of the channel, although two high readings of both parameters were taken on two separate occasions, which resulted in an average increase.
- *Suspended solids:* The channel reduced TSS more than 50% of the time, however, high value readings (likely caused by resuspension of sediment during sampling) resulted in a TSS average increase of 119%.
- *Metals:* During low flows, zinc (the only heavy metal routinely present in the pond) was measured at higher concentrations upstream than downstream, while during higher flows, the opposite was true. On average, arsenic and chromium levels increased at the outlet, while copper, mercury and zinc decreased.
- *Sediment chemistry:* Concentrations of every heavy metal measured declined significantly except chromium, which was slightly higher downstream than upstream on one occasion. The effective removal of arsenic was 44.7%, cadmium 83.4%, chromium 19.8%, copper 39.9%, lead 90%, mercury 58.3% and zinc 64.7%.
- *Bacteriology:* Both fecal coliform and Enterococci were lower downstream than up on every date except one. Enterococcus values never exceeded 12 CFU.

Compliance:

- *Water:* Guidelines were exceeded once for arsenic, once for chromium, and four times for both copper and Mercury.
- *Sediments:* Upstream, arsenic levels were exceeded once, and cadmium, chromium and mercury levels twice. Cadmium was just over the limit downstream on one occasion as well. Copper exceeded in all samples upstream and downstream except one.

Summary: Because of its slow flow, Blenkinsop Creek acted as a long pond, and was very effective at removing nutrients. Increased sinuosity of the restored channel increased the residence time of water, which encouraged particle settlement and hence pollution removal. Other than zinc and arsenic, the creek had very low metal concentrations, and the markedly lower metals concentrations in downstream sediments suggests that Blenkinsop Lake is the source of most metals in the creek, not the neighbouring fields. The creek also had extremely low dissolved oxygen values, likely due to the anoxic conditions of Blenkinsop Lake, and so cannot support fish at present.

Leeds

Results:

- *Nutrients:* On all but one sampling date, the lower reach of the creek had significantly less nitrogen than the inlet culvert; discounting one anomalous reading, average removal rates were 45.2%. The stream also removed phosphorus on all dates except for two, which were high flow periods when residence time may not have been long enough for the stream to assimilate the nutrients.
- *Suspended solids:* Leeds Creek flows quickly most of the year, and does not allow many particulates to settle, so dissolved solids increased on most sampling dates. The creek did strip some chloride, however.

- **Temperature:** Water temperature was reduced an average of 2.12°C from inlet to outlet.
- **Metals:** Because suspended materials did not settle out, neither did metals, and no reduction in metals was noted.
- **Sediment chemistry:** In the fall, the concentrations of all key metals (except lead) were higher downstream than upstream. In winter and spring, however, this trend was reversed, likely because of a spring flush of sediment, and downstream concentrations of arsenic, chromium, copper, lead and zinc were lower than those measured upstream.
- **Bacteriology:** The fecal coliform counts at the culvert inlet were high, reaching a peak value on February 6, 2007 of 50800 CFU/100 mL and 1.1 CFU of Enterococcus.

Compliance:

- **Water:** Upstream water exceeded the arsenic guideline once. Water from both sites exceeded criterion for copper on eight occasions, chromium on three, lead on nine, and mercury on five. Zinc levels were exceeded once at the inlet and seven times at the outlet.
- **Sediments:** Arsenic, cadmium and lead guidelines were each exceeded once at the outlet. Lead was also exceeded at the inlet twice. Chromium and zinc levels were close or above guidelines at all sites on all sampling dates, except on October 2006 at the inlet. Copper levels were consistently exceeded in all samples. Mercury was high at the outlet twice, and exceeded guidelines at the inlet once.
- **Bacteriology:** In compliance.

Summary: Leeds creek was very effective at removing heat, nitrogen and ortho-P from the stormwater, except during high flow events. However, the creek flows too quickly to effectively remove metals and all but the heaviest suspended sediments.

Comparison to Conventional Stormwater Best Management Practices

To compare study site results with those in the BMP database, median inflow and outflow values were calculated using only those samples that were detectable. This gave a rough estimate only, and so comparisons serve only to assess Saanich wetland performances and to determine whether they should be maintained differently, or if they should be replaced by more traditional stormwater treatment processes.

Findings:

- **Cadmium:** The median outflow cadmium concentration in Baxter Pond (the only project with enough cadmium data for comparison), was approximately half the lowest database outflow value, and so the pond appears to perform as well as any other BMP in this respect.
- **Copper:** Willowbrook and Glanford wetland copper removals were comparable to those of detention pond and biofilter BMPs. Baxter, Blenkinsop and Leeds were not effective at removing copper.
- **Chromium:** Chromium was not commonly present in Saanich stormwater, except in Leeds Creek, which flows too fast to effectively remove this constituent.
- **Lead:** Blenkinsop did not have enough measured lead values for comparison. Willowbrook and Glanford both exported lead, although the effluent values were still well within the range of waters treated by biofilters, hydrodynamic systems and wetlands, and were well below effluent values for detention ponds.
- **Zinc:** Both Baxter Pond and Blenkinsop Creek were as effective at reducing zinc as any other BMP, except a wet pond. Glanford and Willowbrook were net zinc exporters.
- **Total Suspended Solids:** Glanford's TSS effluent quality superseded all the BMPs, while Blenkinsop was easily within the range of a detention pond and biofilter system. Baxter Pond and Leeds Creek did not remove TSS, and Willowbrook exported TSS.

- *Ortho-P*: Only Blenkinsop Creek was effective at removing ortho-P; the other installations studied were net exporters. A similar trend is recorded in the BMP database, where wet ponds have little effect in total phosphorous, and biofilters are net exporters.
- *Nitrate*: Overall nitrate reduction was significant at every site except Blenkinsop, whose data is skewed by the exclusion of non-detectable values, but which removed 20% nitrate on average. Willowbrook is most similar to a wet pond, while Glanford and Baxter are comparable to a detention pond and biofilter.
- *TKN and Total Nitrogen*: Willowbrook and Baxter were net exporters of TKN but reduced total nitrogen and nitrate at a rate comparable to a wet pond or wetland basin. Blenkinsop removed TKN and Total N at rates comparable with a wet pond, while Glanford superceded all the BMPs at removing TKN, and was comparable to a wetland basin in its ability to remove Total N.
- All sites, at different times, did not meet the criteria outlined in the Canadian Water Quality Guidelines for Protection of Aquatic Life for heavy metals.
- Streams can be made more effective by improving their functional condition. The increased sinuosity and retention time in Blenkinsop Creek near Galeys' farm also make it effective at trapping sediment and removing metals and nutrients.
- Unlike engineered wet ponds, the systems studied provide wildlife habitat, views, carbon sequestration, thermal regulation, and also act as a buffer for neighbouring streams.

IMPLICATIONS FOR HOUSING INDUSTRY

Ecological solutions can be as or more effective than traditional best management practices for managing and treating stormwater, and should be considered for inclusion in new and existing developments. Given the added aesthetics of such installations, they may also add perceived value to developments.

CONCLUSIONS

- The Saanich treatment systems, even small ones like Glanford, effectively treat stormwater pollutants, and their performance is comparable with Best Management Practices recorded in the International Stormwater BMP database.
- The Willowbrook and Baxter Pond wetlands need maintenance. Sediment should be routinely cleaned out to prevent the export of suspended solids and associated metals.
- The Willowbrook and Glanford wetlands, Leeds Creek and Baxter Pond all significantly reduced effluent temperatures, which is a key factor in protecting Blenkinsop and Swan Creeks and the salmon habitat of the Colquitz River.

Research Highlight

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Housing Research at CMHC

Under Part IX of the *National Housing Act*, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research.

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